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Physics Department	**590 Commonwealth Ave.** **Boston, MA 02215** **United States**
PI/PD FAX NUMBER **617-353-9393**	

NAMES (TYPED)	Social Security No.*	High Degree, Yr	Telephone Number	Electronic Mail Address
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I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Date
PI/PD Ulrich Heintz		
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Certification for Authorized Organizational Representative or Individual Applicant:

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NAME/TITLE (TYPED)		

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Project Summary

This is a proposal for an integrated research and education program geared towards understanding the origin of electroweak symmetry breaking. Educational activities aimed at students of all levels are integrated into the program. They range from participation of undergraduate and graduate students in design and construction of state-of-the-art research instrumentation, and data analysis with opportunities for several Ph. D. theses, to course development and outreach activities.

The proposed research will use the DØ detector at the Fermilab Tevatron proton-antiproton collider. The next Tevatron run, scheduled to begin in 2000, will allow precise measurements of the W boson and the top quark masses. By comparing these measurements to Standard Model predictions the size of radiative corrections to the W boson mass can be inferred and the Higgs boson mass can be constrained, which provides a consistency test of the Standard Model. With sufficient integrated luminosity, a direct search for the Higgs boson in a very interesting mass range can also be performed. Thus the results of this research program will shed light on the mechanism of spontaneous breaking of the electroweak symmetry, whose elucidation is one of the most important goals of high energy physics today.

Both top quark and Higgs boson decays produce b quarks which travel several mm before they decay. The decay vertices can be reconstructed using the precise silicon microstrip tracker (SMT) under construction for the DØ detector.

The PI proposes a program to maximize the sensitivity of the DØ experiment for these measurements:

1. improve the pattern recognition capability of the SMT by designing, prototyping and producing detectors which allow measurement of b decay vertices in three dimensions;
2. increase the number of events containing b quarks that can be recorded for offline analysis by designing and building a trigger processor for the SMT data;
3. develop analysis tools and techniques to identify b quarks;
4. use these tools to reconstruct top quark decays and measure the top quark mass with significantly increased precision, search for the Higgs boson and signals for new phenomena.

I plan to integrate student researchers into all aspects of this program. This will provide them training in skills essential to a career in high-energy physics.

This research program will build on the PI's thorough knowledge of the DØ detector and his experience with the measurements of the W boson and top quark masses. He already carries significant responsibility for the construction of the DØ SMT and has played a leading role in the development of a proposal for a trigger processor for the data from this detector.

In addition to the educational opportunities integrated into the research program, the PI intends to develop a new topical course on statistical methods for experimental physicists. The PI also proposes to pursue two complementary outreach activities. He intends to participate in the Quarknet initiative to mentor pre-college teachers and to develop a Saturday Academy program which will consist of lectures and demonstrations for high school students.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

*Proposers may select any numbering mechanism for the proposal, however, the entire proposal must be paginated. Complete both columns only if the proposal is numbered consecutively.

1 Introduction

This is a proposal for an integrated research and education program geared towards understanding the origin of electroweak symmetry breaking. The proposed research in experimental particle physics will use the DØ detector at the Fermilab Tevatron. The Tevatron is a proton-antiproton collider with a center-of-mass energy of about 2 TeV, which is currently the highest in the world. The DØ detector is a multipurpose detector, designed to study proton-antiproton interactions at these high energies. It first took data during Run I of the Tevatron from 1992–1996 and has made significant contributions to our understanding of elementary particle physics, including the discovery of the top quark [2], the measurement of its properties [3, 4, 5], the most precise measurement of the W boson mass [6], and searches for new phenomena [7]. Presently the accelerator is undergoing upgrades in preparation for Run II, scheduled to begin in 2000, which will provide 2–4 fb^{-1}, a data set 20–40 times larger than Run I.

The DØ detector as it was operated during Run I is described in detail in reference [1]. It consists of three major subsystems: the central tracker, the calorimeter, and the muon spectrometer. In order to adapt the detector to the anticipated Run II environment, a comprehensive upgrade is underway to all elements of the detector. The entire central tracker is being rebuild. The drift chambers of the Run I detector will be replaced by a scintillating fiber tracker. The upgrade will significantly enhance the capabilities of the central detector by adding a superconducting solenoid that creates a central magnetic field of 2 Tesla, and a silicon microstrip tracker.

Section 2 describes in detail the components of the physics program and my background and expertise in them. Section 3 then gives an overview of the DØ detector and the specific contributions that I propose to make to the upgrade at Boston University. Section 4 describes the proposed educational activities.

2 The Physics Program

2.1 The Standard Model

For the past two decades the Standard Model of the Electroweak Interactions (SM) [8] has dominated how we think of the basic constituents of matter and their interactions. The SM succeeded in describing both the electromagnetic and the weak interactions in the framework of a single gauge theory. The forms of the interactions derive from the requirement of local gauge invariance. The underlying symmetry is spontaneously broken in a way that makes the W and Z bosons massive but leaves the photon massless. To achieve this, the SM has to make very detailed predictions of the properties of the gauge bosons and their interactions which can be experimentally tested. To its great success, the SM is still consistent with the wealth of very precise experimental data.

The SM predicts the existence of a fundamental scalar particle, the Higgs boson, which is the agent of the symmetry breaking mechanism. Its observation and the measurement of its properties would deepen our understanding of the symmetry breaking mechanism, which is at the heart of the SM. To directly observe the Higgs boson or at least constrain its properties is therefore one of the main quests of high energy physics today.

In spite of all its success, the SM leaves us unsatisfied in our desire to understand the basic fabric of matter, because it does not give a compelling description of many phenomena, *e.g.* the fermion masses. These are incorporated into the theory by coupling the fermion fields to the Higgs boson, but the coupling strengths remain free parameters. This has most recently been underlined by the discovery of the top quark and the measurement of its unexpectedly high mass.

It is therefore generally believed that the SM must be incomplete, a limiting case of a more comprehensive theory. It is a challenge for experimental high energy physics to find evidence for the incompleteness of the SM, either directly by observing phenomena beyond the SM, or indirectly by exhibiting inconsistencies between ever more precise measurements and the predictions of the SM. The Tevatron has made unique contributions to this quest during Run I and will continue to do so in Run II and beyond.

2.2 A Consistency Test of the Standard Model

At tree level, the SM relates the masses of the W and Z bosons to the strengths of the electromagnetic and weak interactions and their degree of mixing. It is convenient to choose the mass of the Z boson, the weak coupling constant, and the electromagnetic coupling constant as the fundamental parameters, because they have been precisely measured. Knowing these, the mass of the W boson m_W and the weak mixing angle can be predicted. However, higher order corrections to the tree level predictions are sensitive to other parameters, which are less well known. In the minimal SM, corrections to the W boson mass are dominated by t-$\bar{b}$ loops ($\propto m_t^2$) and W-Higgs boson loops ($\propto \log m_H$).

Figure 1 shows the SM prediction for the W boson mass as a function of the top quark mass. To test this fundamental relationship experimentally, we have to measure the masses of the W boson, the top quark, and the Higgs boson. The measurement of the mass of the W boson by the DØ experiment using the Run I data (80.43$\pm$0.11 GeV) [6] is the most precise value from a single experiment. The world average based on measurements from the Tevatron [6, 10] and LEP2 [11] is 80.375$\pm$0.064 GeV. The top quark mass, based on the measurements by DØ [4, 5] and CDF [12], is 173.8$\pm$5.0 GeV. The mass of the Higgs boson is not predicted by the SM, but we know from experiment that it must be greater than 90 GeV — otherwise it should have been observed at LEP2 [13] — and from theoretical arguments that it cannot be larger than about 1 TeV. As figure 1 shows, the measurements of the W boson and top quark masses are quite consistent with this range of values for the Higgs boson.

The data from Run II will allow significant improvements in the precision of these measurements. DØ expects to measure the W boson mass to about 40 MeV in the $W \rightarrow e\nu$ decay channel from a 2 fb^{-1} data set. This precision from a single decay channel and a single experiment rivals the anticipated precision from all decay channels and all four LEP2 experiments combined (34 MeV [14]). A combination of the measurements from the $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ decay channels by the DØ and CDF collaborations could further improve this number. The top quark mass measurement will reach a precision of about 3 GeV. Thus this fundamental test of the SM will become quite stringent. Figure 1 compares the expected precision of the measurements from the DØ Run II data with that of the current world averages.

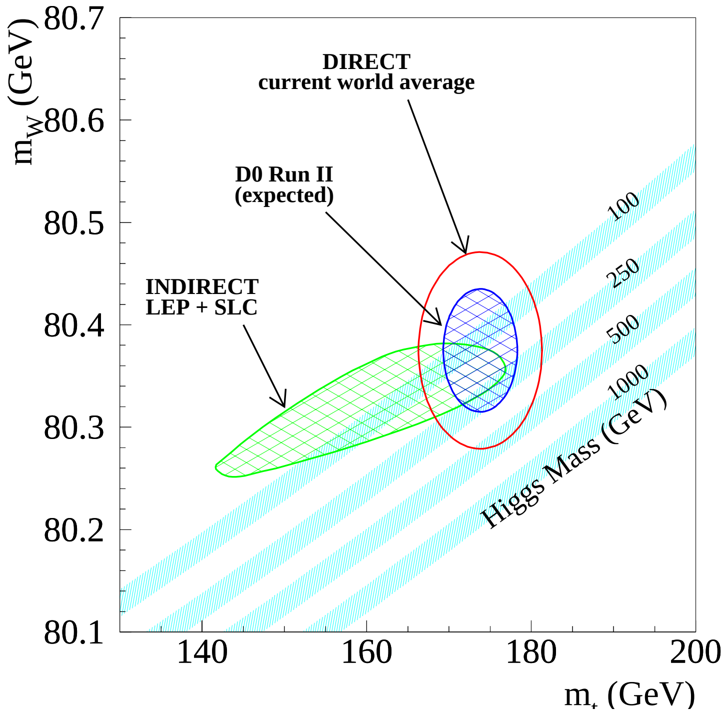

Figure 1: SM prediction of the W boson mass as a function of the top quark mass for different values of the Higgs boson mass. Also shown are indirect experimental constraints from LEP and SLC, the current world average of the direct measurements, and the expected precision of the DØ measurements from Run II.

If the SM is correct, we can constrain the mass of the Higgs boson using the measurements of the W boson and top quark masses. A global fit to all electroweak data, including the W boson and t quark mass measurements, yields $m_H = 115^{+116}_{-66}$ GeV [15]. With the Run II data, the DØ experiment alone will constrain the Higgs boson mass to this precision.

If the SM is not complete, other, presently unknown particles that couple to the W, can give rise to additional corrections to the value of m_W. In the minimal supersymmetric model, for example, additional corrections can increase the predicted W mass by up to 250 MeV [16].

2.3 Measurement of the Top Quark Mass

The study of the t quark will be the exclusive realm of the Tevatron until the Large Hadron Collider (LHC) comes on line. The mass of the t quark has been measured with higher fractional precision than any other quark mass. This is possible because the t quark is so massive that it decays before it hadronizes, providing us with the unique opportunity to study a bare quark.

In $p\overline{p}$ interactions at 1.8 TeV, top quarks are pair-produced with a cross section of 5.5±1.8 pb[3]. To isolate such a small signal from the background we need to tag on the characteristic features of the events. In the SM the t quark decays almost always to Wb. We tag on the leptonic decay of the W to $e\nu$ or $\mu\nu$, the high transverse momentum flow in the events, and the presence of b jets. DØ has measured the mass of the t quark in two decay channels: the lepton+jets channel, in which one W boson decays leptonically, and the dilepton channel, in which both W bosons decay leptonically.

For lepton+jets events we perform 2-C kinematic fits to determine the mass of the top quark. The dominant systematic uncertainties in this measurement are the jet energy scale calibration and the modeling of gluon radiation, which each contribute errors of about 4 GeV to the measurement. The statistical error from the fit to a 77 event sample containing about 25 $t\bar{t}$ decays is 5.6 GeV. We measure $m_t = 173.3 \pm 8.4$ GeV [4]. In dilepton events there are two unobserved neutrinos. The observed final state therefore does not allow a constrained fit. We employ a dynamical likelihood method [17] to define a mass estimator for these events. Based on a sample of six dilepton events we measure $m_t = 168 \pm 13$ GeV [5]. The good agreement between the two mass measurements supports the hypothesis that the observed signal in both channels is due to the decay of the same particle. We combine both measurements to obtain $m_t = 172.0 \pm 7.5$ GeV.

Run I produced just enough top quarks to reliably establish the signal and get a first measurement of the $t\bar{t}$ production cross section and the top quark mass, assuming that the top quark behaves as expected in the SM. Run II will bring a qualitative change in the character of the top physics studies. Rather than assuming that the top quark behaves as predicted by the SM, we will actually be able to test this assumption.

During Run II we expect to accumulate 20–40 times more data than during Run I. For the reconstruction of $t\bar{t}$ decays the silicon microstrip tracker will play a central role. It will allow the detection of the secondary vertices from the decays of the long-lived b quarks. Every $t\bar{t}$ decay contains a b and a $\bar{b}$ quark. We expect to be able to detect the secondary vertex in about 50% of all b quark jets from top quark decays. In addition we will be able to tag 10% of all b quarks by their semileptonic decays. We can use b tagging to reject backgrounds to $t\bar{t}$ decays in the lepton+jets channel. In a 2 fb^{-1} data set we expect to identify about 1000 lepton+jets events with at least one b tag. This significantly larger sample of $t\bar{t}$ decays will allow us to study the production dynamics and the decay branching ratios of the top quark.

Systematic uncertainties due to jet combinatorics in the top quark mass measurement can be significantly reduced by tagging both b quark jets in a $t\bar{t}$ event. Then the number of possible assignments of the four jets to the decay of the t and $\bar{t}$ quarks is reduced from 12 for untagged events to only two. The jets from the W decay will be uniquely identified, allowing reconstruction of the W boson line shape. The reconstructed W signal can be used to calibrate the jet energy scale with the top quark events themselves and reduce the associated uncertainty. We expect at least 400 double-tagged lepton+jets events from 2 fb^{-1}. Another way to reduce the jet energy scale uncertainties is to reconstruct W or Z boson decays to jets. The most promising channel is $Z \to b\bar{b}$, in which b tagging can provide rejection against the dominant gluon jet background.

If we can reduce the systematic uncertainties by about a factor two we should be able to measure the top quark mass to about 3 GeV precision in the lepton+jets channel.

2.4 Search for the Higgs Boson

The TeV2000 Higgs study group [18] concluded that a signal for $H \to b\bar{b}$, produced in association with a W boson that decays to $e\nu$ or $\mu\nu$, can be observed at the Tevatron with an integrated luminosity of 5–25 fb^{-1} (for m_H=80–120 GeV). Upgrades to the Tevatron (TeV33) that would allow the collection of such large data sets before the LHC turns on are presently under consideration.

This mass window is extremely interesting from experimental and theoretical points of view. It straddles the upper edge of the sensitivity range of LEP2 and the lower edge of the LHC's. TeV33 can extend the accessible Higgs mass range before LHC starts running. A Higgs boson in this mass range would be difficult to detect at the LHC and requires b quark tagging at high luminosities to detect $H \to b\bar{b}$ or the detection of the suppressed mode $H \to \gamma\gamma$. Fits to the present electroweak data, assuming the completeness of the minimal SM, prefer Higgs mass values in the range potentially accessible at the Tevatron [15]. In supersymmetric extensions to the SM the lightest Higgs boson is expected to have a mass below about 130 GeV. It is therefore imperative that the window $80 < m_H < 130$ GeV is covered reliably. This will be possible first at the Tevatron.

We do not expect to be able to see a Higgs signal with the integrated luminosity expected for Run II (2–4 fb^{-1}), unless additional decay channels of the associated gauge bosons can be used. Five times as many Higgs bosons are produced along with Z bosons or hadronically decaying W bosons than with W bosons decaying to $e\nu$ or $\mu\nu$. In order to exploit these channels we have to be able to trigger on $q\bar{q}b\bar{b}$ final states, which requires the capability to tag b quark jets already at the trigger level. $Z \to b\bar{b}$ decays are a very important control signal for a search for $H \to b\bar{b}$ decays. They can be used to study the $b\bar{b}$ mass resolution and b-tagging efficiency and to demonstrate the ability to detect a $b\bar{b}$ resonance. A trigger with low enough thresholds on the transverse b jet momenta to be sensitive to $Z \to b\bar{b}$ decays can only be operated if the dominant gluon jet background can be rejected by tagging the b jets at the trigger level (see section 3.2).

A study of $Wb\bar{b}$ final states is interesting for other reasons as well. For example, it has been suggested [19] that the decay $\rho_T \to W\pi_T^0(\to b\bar{b})$ could provide evidence for technicolor. Technicolor theories provide an alternative mechanism for electroweak symmetry breaking that does not involve a Higgs boson. They predict additional pion-like particles ("technipions": π_T) which may decay into b quarks and should be detectable at the Tevatron.

2.5 My Role in the Run I Measurements and Studies

As co-leader of the W mass analysis group during the time that the analyses of the Run Ia and Ib data came to maturity, I pioneered many of the ideas that allowed us to reach this high precision. Under my close supervision, Ian Adam and Eric Flattum, two Ph.D. students from Columbia University and Michigan State University, wrote their dissertations based on the W mass measurement from the Run Ib data. They have now moved on to postdoctoral positions at SLAC and Fermilab. Together with these students I wrote two articles describing the Run Ib W mass measurement [6].

My involvement in the t quark analyses is twofold: I spearheaded the effort to measure the t quark mass in the dilepton channel by developing an algorithm and then leading one of two analysis efforts within the collaboration. The algorithm is based on reference [20] but also includes the

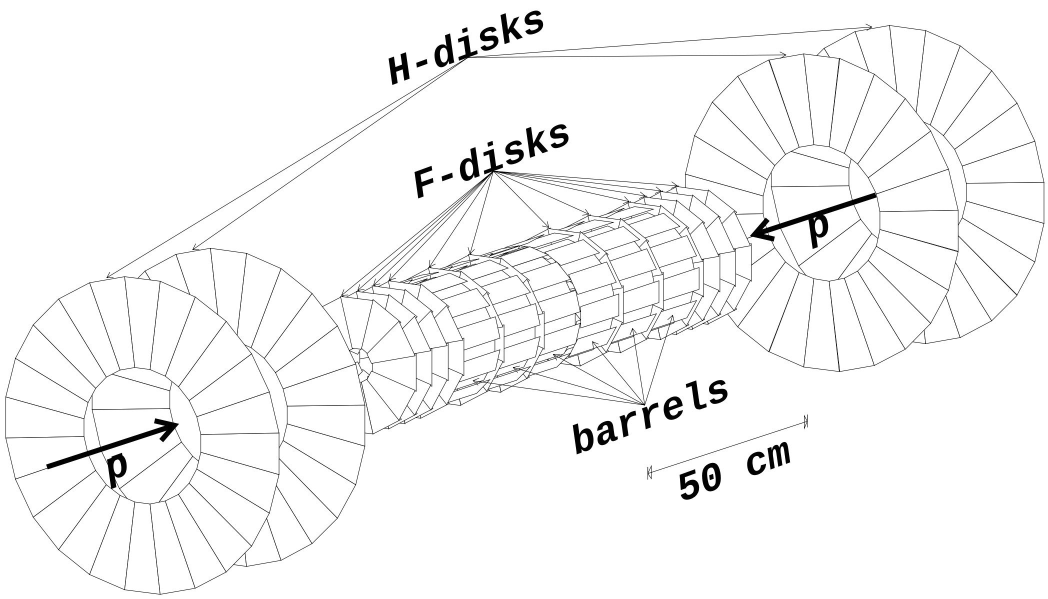

Figure 2: View of the silicon microstrip tracker for the DØ upgrade.

effects of detector resolutions and gluon radiation. The results have been published in Physical Review Letters [5]. Presently, I am writing an article describing the two analyses to be submitted to Physical Review D. I also developed an optimized electron identification algorithm based on a Neyman-Pearson test, which for the first time employed the signal from the transition radiation detector in electron identification and has become the standard for all the t quark analyses (and many others) involving electrons [3].

During the TeV2000 study, I was co-convener of the group that explored the possibility of detecting the Higgs boson at the Fermilab Tevatron.

3 Development of b-Tagging Capabilities for DØ

3.1 Silicon Microstrip Tracker

3.1.1 Detector Components

The DØ silicon microstrip tracker consists of detectors oriented in parallel with the beam (arranged in six barrel sections), and detectors oriented perpendicularly to the beam (arranged in 12 small diameter (F-)disks and 4 large diameter (H-)disks) (figure 2).

The barrel detectors measure the trajectories of charged particles at large angle with respect to the beam with hit resolutions around 10 μm in the azimuthal direction. Taking into account multiple coulomb scattering, this translates into an impact parameter resolution around 30 μm. The mean impact parameter of tracks from the decay of b quarks in $t\bar{t}$ events is about 100 μm. The long barrel region is necessary to cover the extended luminous region of the Tevatron ($\approx$ 25 cm). The F-disks extend the coverage to tracks at smaller angle with respect to the beam.

3.1.2 Barrel Sections

Each barrel section consists of 72 rectangular silicon devices (ladders), 12 cm long, mounted on a beryllium support structure. The ladders are arranged in four concentric layers. Layers 2 and 4 are made of double-sided silicon devices with axial strips parallel to the long edge of the devices on the p-n junction side and 2° stereo strips on the ohmic side. Layers 1 and 3 of the central four barrel sections were originally single sided with axial strips only.

Together with other members of the DØ silicon group, I demonstrated that double-sided silicon devices with axial strips on one side and 90° strips on the other side would enhance the pattern recognition capabilities of the silicon microstrip tracker by allowing to measure the displacement of b-decay vertices in the z-direction (along the beam). The maximal b-tagging efficiency can be achieved only if secondary vertices can be reconstructed from as few as two tracks with high impact parameter. However, any arbitrary two tracks intersect in the transverse plane and create the appearance of a secondary vertex if precise tracking information is only available in the plane transverse to the beam. The addition of the third view adds a constraint to each two-track vertex that allows the rejection of vertices formed by two tracks that are not consistent with originating from the same point in three-dimensional space. The impact parameter resolution in the z-direction has to be of order 100 μm or better to separate the tracks from a b quark decay and those from the primary vertex along the z direction. The 2° devices in layers 2 and 4 achieve a hit resolution of only about 300 μm in the z direction. We therefore need the 90° strips to provide a sufficiently precise measurement of the hit coordinate along the beam direction ($\approx$30 μm) and allow us to reconstruct secondary vertices in three dimensions.

I have designed the wafer layout (figure 3) for these devices. The 90° devices are double-sided with axial strips with 50 μm pitch on the p-n junction side. On the ohmic side they are segmented into strips that form a 90° angle with the axial strips. The strips are formed by implants with high dopant concentrations (p-dopant for the axial strips and n-dopant for the 90° strips). A silicon oxide dielectric and aluminum strips over the implants AC-couple the devices to the readout chips, located at one end of the ladder. In order to carry the signals from the metal strips over the 90° strips to the readout chips, a second metal layer is required. This second metal layer is separated from the first metal layer, which forms the coupling capacitors, by a thick (4 μm) layer of silicon oxide to minimize coupling between the two layers. The traces on the second metal layer run parallel to the axial strips and are connected to the capacitor strips by vias etched into the silicon oxide. The minimum pitch (about 50 μm) between traces in the second metal layer limits the number of readout channels to 384. By connecting two 90° strips to each readout channel we can space the 90° strips closely enough (153 μm) to achieve satisfactory position resolution and cover the full length of the device. The layout shown in figure 3(b) minimizes the overlap area (and thus the capacitance) between the two metal layers by locating the connections to the readout chips as close to the center of the detectors as possible. With this design, we expect a strip capacitance of 15 pF and a signal-to-noise ratio of 17, well above the required minimum of 10.

An order has been placed with Micron Semiconductor Ltd in Lancing, U.K. to manufacture 144 such detectors (plus spares) to be installed in layers 1 and 3 of the four barrel sections closest to the detector center. In order to minimize production and assembly costs, three devices 12 cm in length will be manufactured on 6" silicon wafers (figure 3(c)). The design of the 90° devices

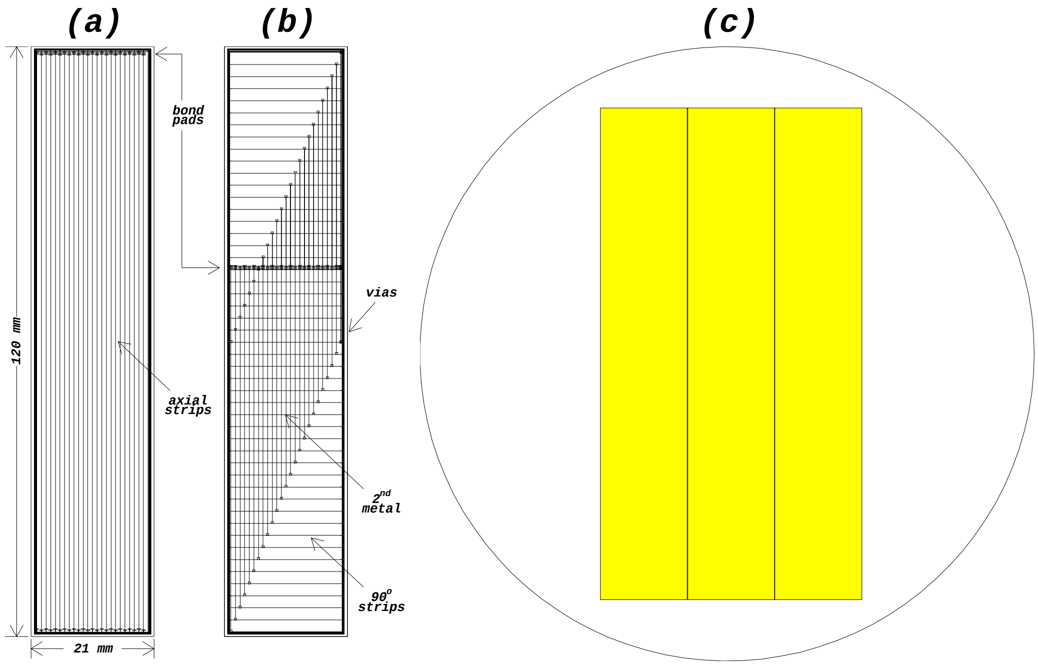

Figure 3: Layout of the p-n junction side (a) and the ohmic side (b) of the 90° detectors. Every 16^{th} strip is shown. Vias connect the two metal layers and bond pads are used to connect the SVX-II readout chip. Figure (c) shows the arrangement of three detectors on a 6" wafer.

poses a particular challenge, because they require the double-metal technology on the ohmic side which has never before been used on the large 6" wafers.

I propose to build up the laboratory infrastructure at Boston University to characterize prototypes of the 90° devices and work with the manufacturer to optimize these devices. The Physics Department at Boston University will provide use of a class 10000 clean room and funds to purchase the major components of the laboratory setup (PC with Labview software, semiautomatic probestation, computer controllable measurement instruments, microscopes).

Prototypes will be tested for radiation hardness at the Fermilab Booster or other facilities, depending on schedule and availability of the booster. The devices in layer 1 will be located about 28 mm from the beam and receive the largest radiation dose of all detector elements. At this radius, we expect a fluence of about 2×10^{13} particles or 0.5 Mrad per fb^{-1}. The radiation damage will result in increased leakage current and depletion voltage. These parameters will be monitored during irradiation to measure their values as a function of the proton fluence.

Finally, after satisfactory performance has been achieved, production testing and quality control will be performed at Boston University before the detectors are shipped to Fermilab for installation into the tracker.

3.1.3 F-Disk Assemblies

The F-disk assemblies are made of 12 trapezoidally shaped silicon devices. They are double-sided devices with strips parallel to the sides of the trapezoid such that they form a 30° stereo angle. They are mounted on alternating sides of a beryllium ring 2.5 mm thick, which also serves as a cooling channel. I have designed the wafer layout for these detectors and I am responsible for design and production of the F-disk assemblies, including the silicon detectors and the mechanical support structure.

3.2 Silicon Track Trigger

3.2.1 The DØ Trigger System

The DØ detector has a three-level trigger system. Level 1 is a deadtimeless trigger using only limited information from the calorimeter, the muon system and the fiber tracker which can be obtained within 4 μs after the interaction. It can accept interactions at a rate of 5–10 kHz. Level 2 consists of dedicated pre-processors which analyze the data from each subdetector in more detail. They pass their results to a global processor which correlates the information from different subdetectors and takes the trigger decision based on the combined information from all subdetectors. Events can be transferred at a rate of 1 kHz to level 3, which is a farm of workstations that perform a limited reconstruction of the entire event. In the present baseline design no information from the silicon microstrip tracker is used in the trigger.

3.2.2 Impact of a Silicon Track Trigger

A level 2 pre-processor for the SMT data would benefit several aspects of the proposed physics program by enriching the data in their b quark content. Without loss of signal, this silicon track trigger would reduce the number of background events that are read out, reducing the readout rate of the detector. This would not only use the bandwidth of the trigger and data acquisition systems more efficiently but also save storage and processing resources throughout the course of the analysis. In some cases to trigger on events with b quark jets is the only way to reduce the trigger rate sufficiently to be able to acquire enough events to see a signal.

Monte Carlo simulations of trigger rates show that triggering on tracks with high impact parameter at level 2 reduces the trigger rate for $t\bar{t}$ decays in the muon+jets and hadronic channels by about a factor three without loss in signal efficiency. It significantly reduces the rate of triggers for $H \to b\bar{b}$, produced in association with hadronically decaying W or Z bosons. Most importantly, it enables an unprescaled trigger for $Z \to b\bar{b}$ decays, which is not possible without rejection against gluon jet background at the trigger level. Table 1 shows the rates and efficiencies at level 2 for these processes with and without the silicon track trigger (STT).

A silicon track trigger would also benefit topics of interest beyond the scope of this proposal, such as b physics. Adding the hits in the silicon microstrip tracker to the hit information from the scintillating fiber tracker would improve the track momentum resolution at level 2 by up to a factor two.

Table 1: Trigger rates at level 2 for $\mathcal{L} = 2 \times 10^{32}/\mathrm{cm}^2/\mathrm{s}$ with and without STT.

process	without STT		with STT	
	rate (Hz)	efficiency	rate (Hz)	efficiency
$t\bar{t} \to \mu + \text{jets}$	113	96%	39	93%
$W(\to q\bar{q}) + H(\to b\bar{b})$	140	74%	20	59%
$Z \to b\bar{b}$	200	35%	60	35%

The DØ collaboration has conducted an internal review which strongly recommended addition of a silicon pre-processor to the trigger system. A proposal to construct a silicon track trigger will be presented to the Fermilab PAC in October 1998.

3.2.3 Conceptual Design

I played a leading role in the development of the conceptual design of the silicon track trigger [21]. This processor goes into action as soon as an event is accepted by the level 1 trigger. It receives the raw data from the SMT front-ends and a list of tracks in the scintillating fiber tracker from the level 1 trigger. The tracks in the scintillating fiber tracker define roads in the SMT about 2 mm wide. A hit filter compares the hits in the SMT to these roads and creates a list of hits inside each road. A track processor then fits a track parametrization to the hits in the scintillating fiber tracker and the SMT hits. The track parameters (momentum, direction, impact parameter) are communicated to the global level 2 processor over a fast link and used in the trigger decision. The time budget for the silicon track trigger processor is about 50 μs.

I propose to design, prototype, and produce the hit filter, which is the core component of the proposed silicon track trigger. The hit filter will be implemented as a VME64 compatible circuit board. Each board receives the data from eight silicon detectors over optical fibers. As the data arrive, the signals from adjacent strips are clustered into hits. The hit positions are compared to the roads and a list of hits inside each road is created. The functionality of the hit filter will be implemented in programmable logic devices, so that the latency introduced by the hit filter will be small (a few μs only). All lists from a given event are stored in a buffer before they are transmitted to the track processor, so that the hit filters are ready to accept data from another event.

For the design of these boards, I will collaborate with the Electronics Design Facility at the Boston University Physics Department. The facility has already successfully collaborated with the DØ group at Boston University in constructing trigger electronics for the DØ muon system. Their expertise in designing fast electronics and familiarity with the DØ experiment will be essential to the successful completion of this project. The facility also has the required design and diagnostics tools needed. The DØ collaboration is presently seeking funding for the engineering and production costs of the silicon track trigger.

This award would allow me to tap into the substantial intellectual resources available at the university to design this device. No collider experiment has yet triggered on b decays using tracks with high impact parameters. The conventional technique (muons from $b \rightarrow \mu\nu c$ decays) is limited by the semileptonic branching fraction of the b quark. The CDF collaboration is pursuing a similar objective relying heavily on custom designed chips, while the design presented here is based on the latest commercially available components. The experience gained in this project will enable future experiments, *e.g.* at TeV33 or the LHC at CERN to design effective triggering strategies for b quarks.

3.3 Funding

To ensure the success of this program, I request the support outlined in the attached budget. The proposed detector development projects must be completed in a timely fashion in accordance with the schedule for the DØ upgrade. To ensure adequate manpower is available for this, partial support for a postdoctoral associate is requested during the first two years of the program. I will supplement this support from seed funds that the university has put at my disposal. The effectiveness of the contribution of the Boston University group to the DØ collaboration will depend on the ability to travel to Fermilab frequently and maintain the close contact with other collaborators that is necessary to ensure that the individual components will fit together into a powerful detector. Funds for travel to Fermilab, to the annual DØ collaboration workshop, and to international conferences, are requested.

3.4 The DØ Group at Boston University

The other faculty member in the DØ group at Boston University is Prof. Butler. He is co-leading the upgrade of the DØ muon system and building part of the muon trigger electronics at Boston University. His interest is in b-tagging and a detailed study of the top quark. Dr. Narain, currently a Wilson Fellow at Fermilab, will join the group as a Visiting Professor in fall 1998. She is responsible for the development of the vertex reconstruction software for the DØ upgrade and is also interested in top physics. Currently the group has no post-doctoral associates. Several theorists in the department are also interested in the top quark and in electroweak symmetry breaking mechanisms, which should ensure a fruitful interchange of ideas between experimentalists and theorists.

4 Educational Activities

4.1 Previous Experience

My desire to teach physics is motivated by several experiences in my career as a physicist:

As a student: beginning with my first contact with science and mathematics in high school, I felt at ease with the subject. Its logical way of thinking appealed to me. So it was natural that I chose to continue my science education at the university level. However, I only developed a passion for and and a real understanding of research when I came to this country as a visiting graduate student at the State University of New York at Stony Brook. There I immediately had the opportunity to become involved in a research project and the enthusiasm of the people I worked with sparked the same feeling in me. I therefore think it is essential to bring young people in contact with research projects as early as possible. Therefore, I am planning outreach to high-school teachers and students.

As a teacher: my first experiences as a teacher were at Stony Brook and Cornell University as a Teaching Assistant, where I taught recitation and lab sections. More recently, as a Wilson Fellow at Fermilab I had the privilege to supervise the thesis research of two of the best graduate students in the DØ collaboration, because their official thesis advisors were not resident at the laboratory. It gave me great satisfaction to see them grow as researchers and develop their own independent ideas under my guidance and it gave me confidence that I would be able to make a difference as a teacher. I am eager to work with students on my research activities and am confident that I can motivate them to further pursue scientific careers.

As a researcher: In conducting research, I have found that understanding the significance of few events or null results is often crucial. The ability to draw scientifically valid, rigorous conclusions from these requires a solid background in statistical methods. Unfortunately, few universities offer formal instruction in this subject and consequently such a background is sadly lacking with many graduate students engaged in high energy physics experiments. Often statistical problems are met with intuition rather than logical analysis. Therefore, I would like to develop a course that will give students the necessary background to enable them to think in a logical way about statistical problems and solve them in a rigorous fashion.

4.2 Integration of Students into Research Program

I want to work in collaboration with graduate students to develop the research programs outlined above. The timing of Run II is perfect for Ph.D. students. They will be able to contribute to the design and construction of the experimental apparatus, take data with it and analyze them for their Ph.D. thesis research. The education of every graduate student in experimental high energy physics should include these elements, but in reality such opportunities are only too rare in high energy physics today.

The physics program provides a choice of topics for Ph.D. dissertations in the areas of top quark physics and the search for the Higgs boson. During Run II, graduate students will spend time at Fermilab and will be actively involved in the operation of the experiment. This will give them the experience of meeting other researchers in the field, discuss current research topics, and collaborate with them in the analysis of the data and the interpretation of the results.

The silicon detector project will provide deep insight in this cutting-edge detector technology for the students. In their hands-on contact with the devices they will learn how semiconductor detectors work, they will gain experience with state-of-the-art instruments used in semiconductor testing, and they will have the opportunity to develop automatic production testing sequences and implement them using the Labview software. Involvement in the radiation tests will give the students the flavor of running an experiment at a user facility. The entire development sequence, followed with participation in the detector assembly and commissioning at Fermilab provides a comprehensive program for a graduate student.

The design process of the silicon track trigger provides the opportunity for a physics or an engineering student to be trained in designing fast digital electronics and simulating the performance of programmable logic devices. Prototype and production testing also provide opportunities for students to gain experience with fast digital electronics and sophisticated testing equipment, like logic analyzers. In parallel with the hardware design there is a need for the development and optimizations of algorithms and the development of a software simulation of the processor. The DØ collaboration has adopted the use of object oriented code design in C++ as its standard for software development and the code development for the silicon track trigger provides the opportunity for students to gain proficiency with these state-of-the-art techniques.

For undergraduate students projects of a more limited scope can be defined during all phases of the program, that will give them the flavor of research in experimental high energy physics and the opportunity to learn the techniques involved. Examples for projects for undergraduate students are: developing software to implement automatic test sequences, measuring the characteristics of silicon detectors, developing a test stand for trigger electronics, simulation studies of pattern recognition algorithms for the trigger, simulation studies of various aspects of the physics program. In my effort to involve undergraduate students in research activities, I expect to receive support from the Boston University Undergraduate Research Opportunities Program.

The budget contains support for a graduate student and for undergraduate students. I intend to seek additional support for undergraduate students from the Boston University Undergraduate Research Opportunities Program.

4.3 Formal Instruction

In the fall semester of 1998, I will teach an introductory course in particle physics for second-year graduate students. This course will give me the opportunity to motivate these students into choosing this field for their thesis research. The challenge of this course is that it should provide both a foundation for students who will pursue their thesis research in this field as well as a concise overview of theory and experiment for students who will specialize in other fields. While a large fraction of the course will be devoted to building up the fundamentals, I will also make the connection to current research topics. In order to give students an incentive to work through original research literature, I will give term paper assignments on topics of current interest in high energy physics instead of a formal final exam. I am also intending to invite other particle physicists in the department to give introductory lectures about their research projects towards the end of the course.

Later on, I am planning to develop a new topical course in statistical methods for experimental physicists. No such course is in the curriculum of the Boston University Physics Department. I believe that such a course would be very useful for students that would like to go into experimental physics. I imagine a two-part course. The first part will cover the basics of probability theory, error propagation, parameter estimation, and hypothesis testing. The second part will address specific problems that arise in experimental research but are often not covered in the standard text books. These include determining the significance of small signals, the combination of results from several, possibly correlated experiments, determination of limits in situations with backgrounds and imprecisely known input parameters. Solutions to these can be illustrated very nicely with current research examples and it will be interesting to challenge the students to come up with their own solutions. On many occasions discussions about the classical and Bayesian approaches to statistics arise. I would like to contrast these two approaches so that the students have an understanding of both approaches. In developing the syllabus for the course I will consult with faculty members outside of high energy physics to make the material more generally useful.

4.4 Outreach Activities

Outreach activities are important to raise the level of scientific literacy and to increase the fraction of the population that pursues higher level scientific education. The best starting point for these objectives is in high schools. I would like to pursue two models of outreach activities:

- teacher mentoring (Quarknet initiative)
- student lectures (Saturday Academy)

I propose to collaborate with my DØ colleagues from Boston University and Northeastern University to get the two institutions involved in the Quarknet initiative. Quarknet is being started by Dr. Barnett (LBL) and Ms. M. Bardeen (FNAL) and 12 initial university centers are planned for 1999. I would like us to form one of these initial centers. Quarknet targets pre-college teachers. University groups involved in experiments at the Tevatron (and ultimately at the LHC) that participate in the program choose two high school teachers every year to participate in an 8-week summer program. Researchers from the university groups take responsibility for mentoring these two teachers and involving them in their research activities, either at the home institution or at Fermilab. After completing the program the teachers, in turn, share their experiences with students and other teachers at their schools. By involving teachers directly in the program, a snowball effect is created that ultimately reaches many more people than originally involved in the program. The experiments will make data available on the world wide web so that the students at these schools can follow the developments at the Tevatron under the guidance of the teachers that were trained during the program. These data could include real-time displays of events as they are recorded by the experiments or simple event data which the students can analyze to understand the event kinematics.

Another approach that I would like to pursue is to develop a Saturday Academy, modeled after the Saturday Morning Physics program at Fermilab. This program for local high school students extends over 10 Saturdays. On each of these Saturday mornings the students attend a lecture given by Fermilab scientists covering topics such as accelerators, detectors, special relativity, particle physics, etc. The lectures are followed by tours of experiments on the Fermilab site. Over the past four years, I have regularly led some of these tours. Giving the tours was always an enjoyable activity, because the students were always impressed and fascinated by the experimental apparatus. And fascination is the first step towards a deeper interest in science.

This template will have to be adapted somewhat for a university setting. I would like to widen the scope from the particle physics focus to include all areas of research in the department. I would also replace the tours of experiments by smaller demonstrations related to research currently being conducted in the department. I would like to develop a demonstration that deals with the use of silicon detectors in tracking charged particles. We could let students look at various detectors under the microscope. They are rather pretty too look at and the small scale of the features should be quite impressive. Then the students could "detect" particles from an α-source with such a detector. Finally, the demonstration could be complemented by a computer simulation showing graphically how particles traverse an array of detectors and how the hits are reconstructed into a track. This could be done by adapting display software being developed for the DØ detector. The budget includes funds to purchase equipment and software to set up such a demonstration and to defray costs for mailings, xeroxing, phone, and food.

The Saturday Academy would interface well with initiatives by other faculty members. Single day events for pre-college students have been organized in the past by Prof. Simmons, a high energy theorist, and Prof. Goldberg, a condensed matter experimentalist in the Boston University Physics Department. The materials from these events could be incorporated into the Saturday Academy program and Profs. Simmons and Goldberg are interested in collaborating in such a project. Boston University has recently started the Center for Educational Outreach to provide support for such activities. This office will help absorb some of the administrative work load and thus will be very useful in organizing a Saturday Academy program.

The two programs outlined above could well feed each other with teachers that have established contact with the university through the teacher mentoring program acting as contacts to select and motivate students to participate in the Saturday Academy program.

5 Conclusions

I have outlined a research program that will maximally use the potential of the Fermilab Tevatron and the DØ detector. It will produce unique results of great interest to the high energy physics community and many opportunities for students at all levels to become involved in a state-of-the-art research project and gain valuable experience for a career in high energy physics or elsewhere.

The proposed detector development for the silicon microstrip tracker is part of the approved baseline program for the DØ upgrade. The proposed silicon track trigger will give the Boston University group an opportunity to add significantly to the baseline program. An investment in both projects will put the Boston University group in an excellent position to play a major role in the study of top quark decays, and direct and indirect measurements of the mass of the Higgs boson. The expertise developed in silicon detector technology and trigger electronics will be an important asset for the participation of this group in future experiments at TeV33 or LHC.

I have outlined two complementary outreach activities that aim to raise scientific literacy among pre-college teachers and students. I would like to initiate a collaboration between Boston University and Northeastern University to participate in the Quarknet initiative to mentor teachers. I also intend to collaborate with some colleagues at Boston University to develop a Saturday Academy lecture and demonstration series for pre-college students.

Departmental Endorsement and Certifications

Boston University and the Physics Department strongly endorse this career development plan. Prof. Heintz's appointment at Boston University, which is effective September 1, 1997, is his first tenure-track appointment.

The Department will make its substantial resources available to support Prof. Heintz in his research. Significant research infrastructure exists within both the University and the department. In addition to conventional resources, such as the science library, Prof. Heintz will have free unlimited access to the computers of the Center for Computational Science, featuring a 192 processor SGI/Cray Origin 2000. Boston University is equipped with a Scientific Instrument Facility, the largest university machine shop in the Boston area. Prof. Heintz will be able to take full advantage of its state-of-the-art computer-controlled machine tools and highly trained shop staff. The Electronics Design Facility, which has engineers and technicians designing and producing custom anolog and digital circuitry, will be available to support the electronics development contained in Prof. Heintz's proposal.

Boston University has already demonstrated a significant financial committtment to Prof. Heintz, including start-up funding totaling $150,000. The University will provide a full nine-month academic year salary to Prof. Heintz. In addition, Prof. Heintz will be released from teaching for one semester during the next two years to work on his research at Fermilab. Boston University provides full tuition remission for graduate students supported on research funds.

Prof. Heintz's teaching plan will help further the educational goals of Boston University and the Physics Department. The Department is committed to excellence in both undergraduate and graduate education. Prof. Heintz's effort to involve undergraduate students in his research will contribute to the high standard of our undergraduate education. We welcome curriculum development efforts and encourage Prof. Heintz to enhance our graduate curriculum with a new course on statistical methods. Our support for Prof. Heintz in this area can be gauged by our having nominated him to participate in the Fall 1998 AAPT Workshop for New Physics Faculty.

The department encourages its members to engage in educational outreach and the outreach activities proposed by Prof. Heintz will complement existing projects. Boston University's new Center for Educational Outreach will be available to support his efforts.

In conclusion, Boston University is committed to the development of Prof. Heintz as both a researcher and a teacher. This support manifests itself in numerous ways, and involves a significant outlay of money. As chairman of the Boston University Physics Department, I attest that if Professor Ulrich Heintz is selected to receive an NSF CAREER award, I will provide him with the proper institutional support for his research and education development plan.

I have read and I enthusiastically endorse this Career Development Plan.

Lawrence R. Sulak
Chairman, Department of Physics
July 20, 1998

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E-mail:	heintz@fnal.gov
Birth:	December 12, 1960 in Stuttgart-Bad Cannstatt, Federal Republic of Germany

Education: 1991 Ph.D. in physics from State University of New York at Stony Brook
1984 Vordiplom in physics from the University of Tübingen, Germany
1980 Graduation from high school (Abitur)

Positions:

since 1997	Assistant Professor, Boston University
since 1995	Wilson Fellow, Fermi National Accelerator Laboratory
1991–1994	Postdoctoral Research Scientist, Columbia University, New York
1985–1991	Graduate Research Assistant, SUNY Stony Brook
1986–1991	Visiting Fellow, Lab of Nuclear Studies at Cornell University
1989	Teaching Assistant, Cornell University
1986	Teaching Assistant, SUNY Stony Brook

Research with the CUSB Collaboration

My thesis research with the CUSB collaboration centered on the observation of radiative transistion between S and P-wave states of the Υ system. I also studied the radiative decay of excited B mesons and obtained indirect evidence for the decay $B_s^* \to B_s\gamma$. I was involved in the construction of a small drift chamber, a silicon pad detector, and an upgrade of the trigger electronics.

Research with the DØ Collaboration

As co-leader of the W mass analysis group during the time that the analyses of the Run Ia and Ib data came to maturity, I pioneered many of the ideas that allowed us to perform the most precise W mass measurement.

In the top quark analysis, I spearheaded the effort to measure the t quark mass in the dilepton channel by developing an algorithm and then leading one of two analysis efforts within the collaboration.

I developed an optimized electron identification algorithm based on a Neyman-Pearson test, which for the first time employed the signal from the Transition Radiation Detector in electron identification and has become the standard for all the t quark analyses involving electrons and many others.

For the TeV2000 study, I served as co-convener of the group that explored the possibility of detecting the Higgs boson at the Fermilab Tevatron.

Publications most closely related to this proposal

1. "A Measurement of the W Boson Mass.", B. Abbott *et al.*, accepted by Phys. Rev. D, Fermilab-Pub-97/422-E.
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5. "Direct Measurement of the Top Quark Mass", S. Abachi *et al.*, Phys. Rev. Lett. **79**, 1197 (1997).

Other Publications

1. "The DØ Detector", S. Abachi *et al.*, Nucl. Instr. and Meth., **A338**, 185 (1994).
2. "$b\bar{b}$ Spectroscopy from the $\Upsilon(3S)$ State", U. Heintz *et al.*, Phys. Rev. **D46**, 1928 (1992).
3. "Sequential Decays of the Υ''", U. Heintz *et al.*, Phys. Rev. Lett. **66**, 1563 (1991).
4. "CUSB-II: A High Precision Electromagnetic Spectrometer", R. D. Schamberger *et al.*, Nucl. Instr. Meth. **A309**, 450 (1991).
5. "Hyperfine Splittings of B-Mesons and B_s Production at the $\Upsilon(5S)$", J. Lee-Franzini *et al.*, Phys. Rev. Lett. **65**, 2947 (1990).

Collaborators

DØ Collaboration (http://www-d0.fnal.gov/ madaras/authorlist.html)

Advisors

Ph.D. thesis: Professor Juliet Lee-Franzini (INFN Frascati, Italy) postdoctoral: Professor P. M. Tuts (Columbia University)

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION: **Boston University**				FOR NSF USE ONLY — PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Ulrich Heintz**				AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ulrich Heintz - assistant professor	0.00	0.00	2.00	$ 12,000	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	12,000	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	8.00	0.00	0.00	24,000	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				17,767	
4. (1) UNDERGRADUATE STUDENTS				2,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				55,767	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				8,424	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				64,191	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				7,600	
2. FOREIGN				2,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,000	
5. SUBAWARDS				0	
6. OTHER				400	
TOTAL OTHER DIRECT COSTS				2,600	
H. TOTAL DIRECT COSTS (A THROUGH G)				76,391	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 63% of MTDC (Rate: 63.00, Base: 76391)					
TOTAL INDIRECT COSTS (F&A)				48,126	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				124,517	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 124,517	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $			
PI / PD TYPED NAME & SIGNATURE* Ulrich Heintz	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** E- Travel**
8 trips to Fermilab @ $800/trip
1 professional meeting @ $1200
1 international conference @ $2000
**** G-6 Other**
communications

SUMMARY PROPOSAL BUDGET   YEAR 2

ORGANIZATION: **Boston University**	FOR NSF USE ONLY	
	PROPOSAL NO.	DURATION (months): Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Ulrich Heintz**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ulrich Heintz - assistant professor	0.00	0.00	2.00	$ 12,360	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	12,360	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	8.00	0.00	0.00	24,720	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				18,300	
4. (1) UNDERGRADUATE STUDENTS				2,060	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				57,440	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				8,677	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				66,117	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				7,600	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,000	
5. SUBAWARDS				0	
6. OTHER				400	
TOTAL OTHER DIRECT COSTS				4,600	
H. TOTAL DIRECT COSTS (A THROUGH G)				78,317	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) % of MTDC (Rate: 63.00, Base: 78317)					
TOTAL INDIRECT COSTS (F&A)				49,339	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				127,656	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 127,656	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $	
PI / PD TYPED NAME & SIGNATURE* **Ulrich Heintz**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

**** E- Travel**
8 trips to Fermilab @ $800/trip
1 professional meeting @ $1200

**** G-6 Other**
communications

SUMMARY PROPOSAL BUDGET — YEAR 3

ORGANIZATION: **Boston University**				FOR NSF USE ONLY — PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Ulrich Heintz**				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Ulrich Heintz - assistant professor	0.00	0.00	2.00	$ 12,731	$	
2.						
3.						
4.						
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	12,731		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (1) GRADUATE STUDENTS				18,849		
4. (1) UNDERGRADUATE STUDENTS				2,122		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				33,702		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,979		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				36,681		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				7,600		
2. FOREIGN				2,000		
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS $ 0						
2. TRAVEL 0						
3. SUBSISTENCE 0						
4. OTHER 0						
(0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				2,200		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				1,000		
5. SUBAWARDS				0		
6. OTHER				400		
TOTAL OTHER DIRECT COSTS				4,600		
H. TOTAL DIRECT COSTS (A THROUGH G)				50,881		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) % of MTDC (Rate: 63.00, Base: 50881)						
TOTAL INDIRECT COSTS (F&A)				32,055		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				82,936		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 82,936	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI / PD TYPED NAME & SIGNATURE*: Ulrich Heintz	DATE			FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE			Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 3

**** E- Travel**
8 trips to Fermilab @ $800/trip
1 professional meeting @ $1200
1 international conference @ $2000
**** G-6 Other**
communications

SUMMARY PROPOSAL BUDGET YEAR 4

ORGANIZATION **Boston University**			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Ulrich Heintz**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ulrich Heintz - assistant professor	0.00	0.00	2.00	$ 13,113	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	13,113	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				19,415	
4. (1) UNDERGRADUATE STUDENTS				2,185	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				34,713	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,068	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				37,781	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				7,600	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,000	
5. SUBAWARDS				0	
6. OTHER				400	
TOTAL OTHER DIRECT COSTS				3,600	
H. TOTAL DIRECT COSTS (A THROUGH G)				48,981	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) % of MTDC (Rate: 63.00, Base: 48981)					
TOTAL INDIRECT COSTS (F&A)				30,858	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				79,839	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 79,839	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI / PD TYPED NAME & SIGNATURE* **Ulrich Heintz**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 4

**** E- Travel**
8 trips to Fermilab @ $800/trip
1 professional meeting @ $1200

SUMMARY PROPOSAL BUDGET — YEAR 5

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Boston University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Ulrich Heintz

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ulrich Heintz - assistant professor	0.00	0.00	2.00	$ 13,506	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	13,506	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				19,997	
4. (1) UNDERGRADUATE STUDENTS				2,251	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				35,754	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,160	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				38,914	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				7,600	
2. FOREIGN				2,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,000	
5. SUBAWARDS				0	
6. OTHER				400	
TOTAL OTHER DIRECT COSTS				3,600	
H. TOTAL DIRECT COSTS (A THROUGH G)				52,114	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) % of MTDC (Rate: 63.00, Base: 52115)					
TOTAL INDIRECT COSTS (F&A)				32,832	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				84,946	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 84,946	$

M. COST SHARING PROPOSED LEVEL $ 0 — AGREED LEVEL IF DIFFERENT $

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
Ulrich Heintz		INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET COMMENTS - Year 5

**** E- Travel**
8 trips to Fermilab @ $800/trip
1 professional meeting @ $1200
1 international conference @ $2000

SUMMARY PROPOSAL BUDGET   Cumulative

ORGANIZATION **Boston University**	FOR NSF USE ONLY PROPOSAL NO. / DURATION (months): Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Ulrich Heintz**	AWARD NO.

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Ulrich Heintz - assistant professor	0.00	0.00	10.00	$ 63,710	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	10.00	63,710	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (2) POST DOCTORAL ASSOCIATES	16.00	0.00	0.00	48,720	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (5) GRADUATE STUDENTS				94,328	
4. (5) UNDERGRADUATE STUDENTS				10,618	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				217,376	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				26,308	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				243,684	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				38,000	
2. FOREIGN				6,000	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				7,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				5,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				5,000	
5. SUBAWARDS				0	
6. OTHER				2,000	
TOTAL OTHER DIRECT COSTS				19,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				306,684	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				193,211	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				499,895	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 499,895	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $	
PI / PD TYPED NAME & SIGNATURE* **Ulrich Heintz**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date Of Rate Sheet / Initials - ORG

BUDGET EXPLANATION PAGE

A1. Assistant Professor Ulrich Heintz: 2 months of summer support per year at a rate equivalent the PI's academic year salary. Assume 3% increase each year.

B1. Postdosctoral Associate: 8 months each for the first two years at a rate equivalent to $36000/year. This rate is comparable to the compensation paid to others in similar positions within and outside Boston University. This will be suplemented with 4 months support from the PI's seed funds for the first two years. Assume 3% increase each year.

B3. Graduate student support: Based on standard rate of $1437.5/month for 1998, set by College of Arts& Sciences. Assume 3% increase for 1999 and each subsequent year.

B4. Undergraduate student support.

C. Fringe benefits at current rate of 23.4% of professional salaries.

E1. Domestic Travel: 8 trips/year Boston-Fermilab ($800/trip), 1 professional meeting ($1200).

E2. Foreign Travel: 1 international conference ($2000) every other year.

G1. Materials and supplies: $200/year to support research program, based on past experience. $1000/year in years 2–5 to support xeroxing, mailing, food, etc. for Saturday Academy. $1000 in years 2 and 3 for demonstration equipment.

G2. Publication costs: $1000/year based on past experience.

G4. Computer services: $1000/year based on past experience.

G6. Communications: $400/year based on past experience.

I. Indirect cost at Boston University's rate for on-campus research of 63.0%.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Ulrich Heintz**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Real-Time Image Processing for fast Pattern Recognition**

Source of Support: **NSF-KDI**
Total Award Amount: $ **836,378** Total Award Period Covered: **10/01/98 - 09/30/00**
Location of Project: **Boston University**
Person-Months Per Year Committed to the Project. Cal: **2.00** Acad: Summ:

Support: ☐ Current ☐ Pending ☒ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Research in Particle Physics, Task A: Colliding Beams**

Source of Support: **DoE**
Total Award Amount: $ **390,000** Total Award Period Covered: **02/01/99 - 01/31/00**
Location of Project: **Boston University**
Person-Months Per Year Committed to the Project. Cal: **3.00** Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **For the project the shared use of 725 sqft of recently renovated laboratory space, assigned to the D0 group, and 550 sqft class 10000 clean room, are available in the Physics Department.**

Clinical: **none**

Animal: **none**

Computer: **University funds are available for desktop computing.**
Free access to the 192-processor SGI Origin2000 supercomputer in the Center for Computational Science.

Office: **The department provides an office for the PI.**

Other: **Access to Electronics Design Facility with full-time staff of three engineers and two technicians. It offers advanced electronics design, prototyping, and testing capability in support of our research program. Custom integrated circuit (IC) and printed circuit board (PCB) design is done in-house on state-of-the-art CAD tools, including a system provided by Mentor**

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

Continuation Page:

OTHER FACILITIES (continued):

Graphics under their Higher Education Program.
It maintains various test setups to support the data acquisition standards currently in widespread use (NIM, CAMAC, VMEbus, GPIB) and has significant expertise in data acquisition software.
See http://ohm.bu.edu/edf.html for current information.

Access to Scientific Instrument Facility. This facility is a superbly equipped machine shop with a shop director, a staff of eight machinists, a welder, and an assembly director. The shop has over 10,000 square feet of climate-controlled workspace with truck access, crane coverage, and a high bay area. It has a full complement of modern and computer-controlled machines: vertical and horizontal mills, high-capacity lathes, high-precision lathes, a boring mill, five CNC knee mills, and a grinder. The shop also has all the machinery needed for stock preparation, including a large shear, an automatic cutoff saw, and a large bending brake. In addition, the shop has complete welding and leak-checking capabilities.